Effects of meteorological conditions on waterfowl population and intake reasons: measured by rehabilitation center data

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Dr. Lisa Whitenack	**Date**	**Dr. Kelly Pearce**	**Date**

Pledge

TABLE OF CONTENTS

Acknowledgments……4

Abstract……5

Introduction……6

Methods……12

3.1 Waterfowl Species……12

3.2 Data Collection……13

3.3 Meteorological Data……13

3.4 Analysis……14

Results……14

Discussion……28

5.1 Limitations……28

5.2 Hypotheses……29

5.3 Meteorology & Location……32

5.4 Broader Connections……33

5.5 Future Research……33

Conclusion……34

References……35

Appendix……47

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1 | ABSTRACT

Aquatic environments are at great risk because of global climate change and the associated warming of atmospheric temperatures. Freshwater ecosystems are experiencing changes in temperature and volume of water. These fluctuations of physical properties impact organisms that rely on freshwater ecosystems. Waterfowl are a group of bird species that spend most of their life in these habitats and depend on the health of the ecosystem for food, safety, and nesting. Waterfowl that are ill or injured may be taken in by a wildlife rehabilitation program. Wildlife rehabilitators are important in the conservation of these species and have records of waterfowl intakes dating back for decades. Using these records, changes in temperature and precipitation can be linked to the population and health of waterfowl in the area. In this study, 19 species of waterfowl and 3,465 records from the Lake Erie Nature and Science Center in Northern Ohio were used to determine if these shifts in meteorology could explain variations in species composition, intake reason, and age. It was found that temperature is a better indicator of waterfowl intakes with the variable being able to explain 21% of variation in species composition, 15% of variation in intake reason, and 24% of variation in age of waterfowl. Mallard, Canada Goose, and Wood Duck were the species most commonly taken in. The most common reason for intake was being orphaned, hit by a car, or injured by something unknown. For age, nestlings were most commonly taken in. I aim to provide a foundation for the Lake Erie Nature and Science Center's rehabilitation program going forward, with the impacts of climate change on waterfowl in mind.

2 | INTRODUCTION

Levels of atmospheric carbon dioxide have continued to climb since the beginning of the Industrial Revolution in the 1700s (Keeling & Whorf, 1994; Monnin et al., 2001; Neftel et al., 1985). With increasing carbon dioxide levels comes a rise in global climate shifts due to excess heat trapped in the atmosphere (Fischer & Schär, 2010; Miralles et al., 2014; Pörtner et al., 2022; Vose et al., 2017; Wehrli et al., 2019). Meteorological rates of precipitation, temperature, weather pattern frequency, and intensity, are expected to increase (Pörtner et al., 2022; Trenberth, 2011; Van Aalst, 2006; Vose et al., 2017); these changes have already begun to manifest as shown by record highs and lows of average annual global temperature and precipitation (Donat et al., 2016; Lehmann et al., 2015; Zhang et al., 2013). Estimated rates for global biodiversity loss from these climate change impacts continue to increase, but species not directly threatened with extinction also face countless threats from environmental and meteorological changes (Doherty et al., 2016; Urban, 2015; Woinarski et al., 2015).

Water temperatures are increasingly rising with global climate change and meteorological shifts, with no slowing of progression (Allen et al., 2005; Pörtner et al., 2022). Rising temperatures particularly impact water due to high specific heat and changes in hydrologic patterns (Van Vliet et al., 2013). With the heat of warming temperatures comes increased rates of evaporation from freshwater sources and transpiration from vegetation in the ecosystem (Allan et al., 2005). Water flow is heavily affected by the timing, amount, and intensity of precipitation events which may disturb ecosystem processes and inhabitants (Carpenter et al., 1992). Sudden high-intensity precipitation events can result in flashy streams that destroy habitats and displace organisms with highly specific niches (Fisher et al., 1982; Poff & Ward, 1989). Freshwater resources and organisms are further impacted by given vulnerability from fragmented habitats,

climate dependency, and numerous direct and indirect anthropogenic stressors (Arnell & Gosling, 2013; Ashmore & Church, 2000; Palmer et al., 2009; Woodwardet al., 2010). Waterways have historically been altered by human activity, but never at this scale with a multitude of biological elements being threatened (Goel, 2006; McCartney, 2009). Wildlife that depends on these freshwater sources have a limited capacity to move because of the fragmentation, human-built barriers, and naturally occurring barriers. Semi-aquatic species such as waterfowl have more ability to move between habitats but are similarly restricted by these boundaries and their impacts on aquatic prey species (Henry et al., 2016; Overton & Casazza, 2023). Quality and quantity of water resources, which continue to shift with meteorological changes, restrict these populations through the availability of habitat and food (Henry et al., 2016; Overton & Casazza, 2023).

One of the many water-dominated ecosystems experiencing these shifts is wetlands. Wetlands are a freshwater and coastal ecosystem expected to experience impacts in area, distribution, and biogeochemistry. Over half of all wetlands in the conterminous United States have been lost in the past two and a half centuries due to agriculture, urban development, associated drainage and runoff, management of the coast and waterways, pollution, and more recently: climate change (Dahl, 1990; Dahl & Johnson, 1991; Dahl, 2006). With climate change comes fluctuations in precipitation and air temperature extremes that influence wetland biological, chemical, and physical attributes. Fluctuations in precipitation change wetland soil moisture and can give rise to anoxic conditions (Han et al., 2018; Trenberth, 2011). A lack of dissolved oxygen can be fatal for aquatic flora and fauna, as well as the species that rely on these organisms for food. Fluctuation of air temperature, as a main driver of biological processes, changes the speed of nutrient cycles and the amount of possible uptake in bodies of water (Elser

et al., 2007; Lutz et al., 2007). Shifts in nutrient cycles can drastically alter the biogeochemistry of wetlands and how they function as habitats.

Wetlands have seen major changes over time through human impacts as populations and associated settlements have historically continued to expand. The Great Lakes region was once home to a plethora of wetlands that have since been eradicated and modified by said expansion. Marshes used to naturally change with the Great Lakes water levels until they were embanked and experienced an increase in buffer management practices (Herdendorf, 1992; Mitsch & Hernandez, 2013). Natural reactions that wetlands once had to meteorological changes have been suppressed by anthropogenic intervention. The balance that exists between meteorological conditions and wetlands has only been further worsened with climate change. One considerable wetland that has been lost is the Black Swamp, one of the largest wetlands in North America that used to be located in Northwestern Ohio (Kaatz, 1955). The Black Swamp was drained in the mid-1800s and the land was converted into farmland (Blakely, 2019).

This wetland was a major habitat for waterfowl in the Great Lakes region. North American waterfowl are species of semi-aquatic birds under the family Anatidae, which includes but is not limited to ducks, geese, and swans (Owen & Black, 1990). Semi-aquatic birds spend a good amount of their time in the water outside of nesting and resting. They often rely on algae, vegetation, insects, small invertebrates, and fish for food (Owen & Black, 1990). The presence of waterfowl is critical for the health and maintenance of wetlands. Waterfowl's eating habits trim vegetation underwater, on the water's edge, and on land. Trimming has been shown to stimulate plant growth and increase the rate of production (Owen & Black, 1990). As a group of species that prey on small fish and invertebrates, waterfowl have a similarly important role in the management and health of those species (Owen & Black, 1990). Waterfowl also act as an

indicator of a wetland's overall health. Waterfowl are sensitive to changes in the environment and have well-known annual migration routes (Gregory & Strien, 2010). The presence of waterfowl indicates that a wetland is healthy enough to sustain the population. Any detours from historically used wetlands during migration further indicate a change in the health of the ecosystem.

One of the main threats to Lake Erie's wetlands is nutrient buildup causing eutrophication and extreme algal blooms (Higgins et al., 2008; Michalak et al., 2013; Watson et al., 2016). Nutrient levels and algal blooms have visible impacts on waterfowl numbers and health. Algal blooms resulting from a rise in nutrients are directly related to botulism as the illness is caused by ingestion of bacterium commonly found in red tides (Bongers & Tetenburg, 1996; Pearson & Jensen, 1994). Pathogens such as botulism and avian influenza are an area of continuous concern with recent rises in waterfowl cases (NCIRD, 2022; Hénaux & Samuel, 2011; Hess & Paré, 2004; Reed et al., 2003; Teitelbaum et al., 2023; Traill et al., 2009). Furthermore, increases in temperature and precipitation rates have magnified the spread and severity of these algal blooms through sped-up nutrient cycles and greater runoff (Elser et al., 2007; Lutz et al., 2007). Greater and more extreme algal blooms mean that more waterfowl populations are impacted by bacteria-borne illnesses.

Waterfowl have been further impacted by temperature variation altering migration patterns and timing. Warmer weather patterns have been linked to delays seen in waterfowl migration patterns. There have been recorded delays in migration to Southern regions in the fall (Lehikoinen & Jaatinen, 2012). During winter weather extremes, waterfowl have not migrated to as high of latitudes as they have historically (Masto et al., 2022). Furthermore, waterfowl have migrated and arrived early in the spring months (Hüppop & Hüppop, 2003; Rainio et al., 2006).

With an early arrival in the spring has come an advanced associated breeding season (Hüppop & Hüppop, 2003; Jonzén et al., 2006). This could make waterfowl populations more vulnerable as the early arrival of ducklings, goslings, and cygnets will not line up with necessary seasonal changes. Temperature differences may have significant impacts in terms of habitat and food for offspring and waterfowl established to travel to the area. Young waterfowl may not yet be adept at surviving these changes and adults may find a scarcity of food.

Climate change impacts have the potential to disrupt populations of waterfowl in Northern Ohio through the alteration and disturbance of wetlands. Disruptions from fluctuations in precipitation and air temperature extremes inherently threaten the health conditions and seasonal timing of waterfowl. Precipitation fluctuations change the area and distribution of wetlands. Air temperature extremes shift biogeochemical processes, change migration patterns, and delay breeding season. These meteorological fluctuations and extremes further threaten waterfowl populations. Changes in precipitation and temperature have increased the rate at which the surface area of wetlands is expanding or shrinking, thus affecting the maximum population of waterfowl that the wetlands can support (Hansson et al., 2005; Shaw & Fredine, 1956). In addition, each waterfowl species prefers certain conditions, which means that species composition may change with the impacts on wetlands. Dabbling ducks generally prefer shallow water (less than 30 centimeters) in smaller intermediate wetlands, whereas diving ducks generally prefer deeper water (greater than 30 centimeters) in brackish and saline wetlands (Heitmeyer & Vohs Jr, 1984; White & James, 1976). Geese generally prefer deep-water habitats while swans generally prefer lakes over 30 hectares in size with shallow depth (Dorak et al., 2017; Earnst & Rothe, 2004; Squires et al., 2001). Within these broad categories of waterfowl, each species further has different preferences based on depth, salinity, and food type.

Meteorological fluctuations impacting wetland area and distribution may therefore affect species population and composition along with the health and historically known seasonal timing of waterfowl.

With so many expected climate change impacts, waterfowl population, species composition, health conditions, and biological timing have all changed (Moore, 2011). It is important to observe these trends as climate change impacts continue to become more extreme with increased atmospheric carbon dioxide levels. Wildlife rehabilitation centers have generally been useful for surveilling these waterfowl populations and the prevalence of pathogens over long periods (Randall et al., 2012; Yabsley, 2019).

Freshwater ecosystems like wetlands are likely going to continue to be further affected by the meteorological impacts of climate change. Seasonal temperature differences may affect the migration and breeding of waterfowl due to biological seasonal timing and biogeochemical processes. Increased temperature could disrupt the natural timing of waterfowl species that migrate south for the colder months and north for the warmer months. Changes in precipitation could alter freshwater availability, habitats, and resources through fluctuations in wetland area, distribution, prey species, vegetation, and increased runoff altering water chemistry. I hypothesize that when climate changes, the population and health conditions of waterfowl will shift. If there are higher than historical average amounts of precipitation, then there will be an increase in waterfowl population due to an increase in wetland surface area. This should be mirrored in wildlife rehabilitation records, but will also be compared against government-recorded population counts. If there is little change in population count, but an increase in rehabilitation intakes, then this could point towards an overall decline in the health of the wild population. If there are lower than average historical amounts of precipitation, then the

opposite will occur and be compared in the same manner. If there are higher than average historical temperatures, then waterfowl will be around the area for a longer period due to natural biological timing dependence on temperature. This will be able to be seen through the wildlife rehabilitation records as waterfowl cases have documented intake dates. If there are lower than average historical temperatures, then the opposite will occur and be seen through the cases as well. Overall, I expect a change in the timing of offspring being brought into the rehabilitation center due to meteorological shifts that have occurred over the past few decades.

3 | METHODS

3.1 Waterfowl Species

Name		Use of land									
		Ohio					Lake Erie				
Common name	Scientific name	Year-round	Migration	Breeding	Nonbreeding	Winter	Year-round	Migration	Breeding	Nonbreeding	Winter
Dabbling ducks											
American black duck	*Anas rubripes*	X			X						
Gadwall	*Mareca strepera*	X	X		X						
Mallard	*Anas platyrhynchos*	X									
Northern pintail	*Anas acuta*		X	X							
Wood duck	*Aix sponsa*	X									
Diving Ducks											
Black scooter	*Melanitta americana*		X							X	
Bufflehead	*Bucephala albeola*		X			X					
Canvasback	*Aythya valisineria*		X			X		X	X		
Common goldeneye	*Bucephala clangula*				X						
Greater scaup	*Aythya marila*		X								X
Hooded merganser	*Lophodytes cucullatus*	X									
Lesser scaup	*Aythya affinis*		X					X			
Long-tailed duck	*Clangula hyemalis*		X							X	
Red-breasted merganser	*Mergus serrator*		X							X	
Ring-necked duck	*Aythya collaris*		X								
Ruddy duck	*Oxyura jamaicensis*		X								
Geese											
Canada goose	*Branta canadensis*	X		X		X					
Other											
Trumpeter swan	*Cygnus buccinator*	X		X		X					
Tundra swan	*Cygnus columbianus*		X								

Table 1. Common and scientific names for all native waterfowl species in Ohio and Lake Erie with known land use for both locations (Cornell Lab of Ornithology, 2024).

All waterfowl that were included in the dataset are native and placed into groups of dabbling ducks, diving ducks, geese, and others (Table 1). Land use (year-round, migration, breeding, nonbreeding, and winter) was listed for each species in Ohio and Lake Erie as a basis for seasonal changes in species composition (Table 1).

3.2 Data Collection

The Lake Erie Nature and Science Center and wildlife staff member Tim Jasinski provided all the data. The Lake Erie Nature and Science Center specializes in waterfowl and is the only wildlife rehabilitation center in Northeast Ohio that takes waterfowl. All data from 2016 to 2023 was electronically available in Excel files. All available data from 1987 to 2016 was manually transferred from physical records to electronic copies and typed into Excel. Each species had its own Excel page. Each page had information on the individual intake number, species, sex, life stage, date first seen, intake date, details of rescue, reason for rescue, injury location, injury, weight, disposition type, and disposition date (see Appendix 1). Variables of interest from the wildlife rehabilitation records were species, age at intake, intake month, reason for intake, and the overall number of intakes.

3.3 Meteorological Data

The National Weather Service was used for gathering weather information on temperature and precipitation (United States, 1999). I used the Cleveland, Ohio, U.S.A. region. Precipitation was recorded in inches per monthly average. Temperature was recorded in degrees Fahrenheit per monthly average. When the month of intake was not known, the annual average for the intake year was used. Variables of interest from the meteorological data were average temperature and precipitation.

3.4 Analysis

My primary goal for analysis was to evaluate any possible connections between the intake data and recorded average meteorological conditions. The dataset included records for 19 species and 3,465 individual intakes. I analyzed the intake data with the meteorological data using detrended correspondence analysis through the program PAST (version 4.03). Detrended correspondence analysis is a refined type of correspondence analysis; the visualization of the relationship(s) between categorical variables. Modifications were made to detrend the visualization by stretching the x-axis to limit an issue known as the "arch effect". This made it easier to see relationships between and within variables.

4 | RESULTS

Detrended correspondence analyses were used to visualize any differences in intake data for waterfowl species with recorded monthly precipitation and temperature averages. Patients and years were excluded if missing a data point. All intake data from the years 2001 to 2004, 2006 to 2009, and 2012 to 2014 were lost as the only copies were physical and discarded by the wildlife rehabilitation center. For years previous to 2011, intake data may be limited and not fully representative.

Species		Temperature (°F)			
Scientific Name	Common Name	0.0-30.0	30.1-50.0	50.1-70.0	70.1+
Aix sponsa	Wood Duck	2	31	232	107
Anas acuta	Northern Pintail	0	1	0	0
Anas platyrhynchos	Mallard	42	306	1043	526
Anas rubripes	American Black Duck	3	4	7	0
Anas spp.	Duck (unspecified)	0	5	33	1
Aythya affinis	Lesser Scaup	5	10	1	0
Aythya collaris	Ring-necked Duck	1	1	0	0
Aythya marila	Greater Scaup	3	2	3	0
Aythya valisineria	Canvasback	10	2	0	0
Branta canadensis	Canada Goose	27	226	470	280
Bucephala albeola	Bufflehead	1	5	1	0
Bucephala clangula	Common Goldeneye	4	3	1	0
Clangula hyemalis	Long-tailed Duck	1	3	0	0
Cygnus buccinator	Trumpeter Swan	0	1	2	1
Cygnus columbianus	Tundra Swan	2	2	0	0
Lophodytes cucullatus	Hooded Merganser	0	1	8	0
Mareca strepera	Gadwall	0	1	1	0
Melanitta americana	Black Scoter	0	0	1	0
Mergus serrator	Red-breasted Merganser	15	12	3	0
Oxyura jamaicensis	Ruddy Duck	4	5	4	0

Table 2. Intake abundance of waterfowl in 4 temperature zones (°F).

The greatest number of intakes occurred during months with an average temperature of 50.1-70 °F which on average were between the months of May through September, shifting to

sometimes include April and October (Table 2). Most species were taken in during months with temperature averages between 30.1 and 70.0 °F which were usually every month except January, July, and August (Table 2). Only five species were taken in during months with temperature averages higher than 70.1 °F; *Aix sponsa*, *Anas platyrhynchos*, *Anas spp*., *Branta canadensis*, and *Cygnus buccinator* (Table 2).

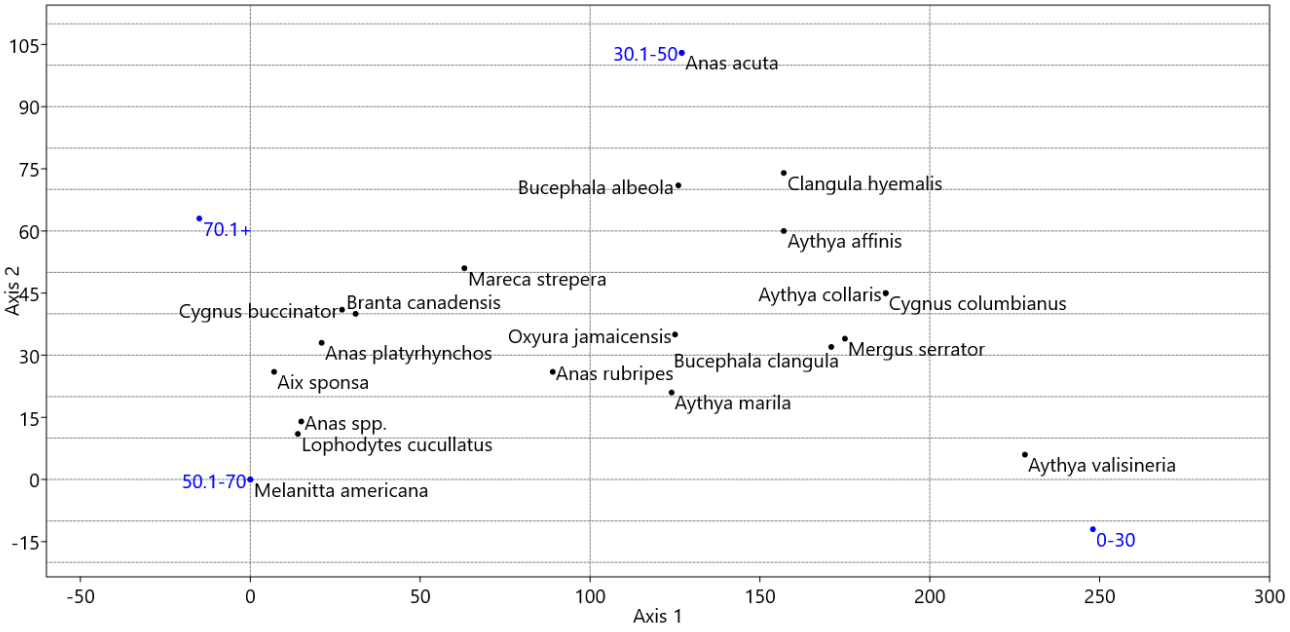

Figure 1. Detrended correspondence analysis for waterfowl intake species and monthly temperature averages (°F).

Axis 1 showed relationships between the two categorical variables (Fig 1). Temperature decreases along axis 1 (Fig 1). Most species were closest to temperature range 30.1-50 (℉) on axis 1 (Fig 1).

Axis	Eigenvalue
1	0.2081
2	0.01003
3	0.001905
4	0.00107

Table 3. Detrended correspondence analysis eigenvalues for waterfowl intake species and monthly temperature averages (°F).

Using detrended correspondence analysis, I found that 20.81% of the variance in abundance of waterfowl species can be explained by monthly average temperature (Table 3).

	Precipitation (inches)		
Species	0.00-0.10	0.11-0.20	0.21-0.30
Aix sponsa	119	92	65
Anas acuta	0	1	0
Anas platyrhynchos	685	939	293
Anas rubripes	10	4	0
Anas spp.	27	12	0
Aythya affinis	9	7	0
Aythya collaris	1	1	0
Aythya marila	5	2	0
Aythya valisineria	12	0	0
Branta canadensis	361	481	161
Bucephala albeola	5	2	0
Bucephala clangula	4	4	0
Clangula hyemalis	4	0	0
Cygnus buccinator	1	2	1
Cygnus columbianus	4	0	0
Lophodytes cucullatus	0	9	0
Mareca strepera	1	1	0
Melanitta americana	0	1	0
Mergus serrator	20	9	0
Oxyura jamaicensis	12	1	0

Table 4. Intake abundance of 20 species in 3 precipitation zones (in).

The greatest number of intakes occurred during months with an average precipitation of 0.11-0.2 inches (Table 4). Most species were taken in during months with precipitation averages

between 0-0.2 inches (Table 4). Only four species were taken in during months with precipitation averages higher than 0.21 inches; *Aix sponsa*, *Anas platyrhynchos*, *Branta canadensis*, and *Cygnus buccinator* (Table 4).

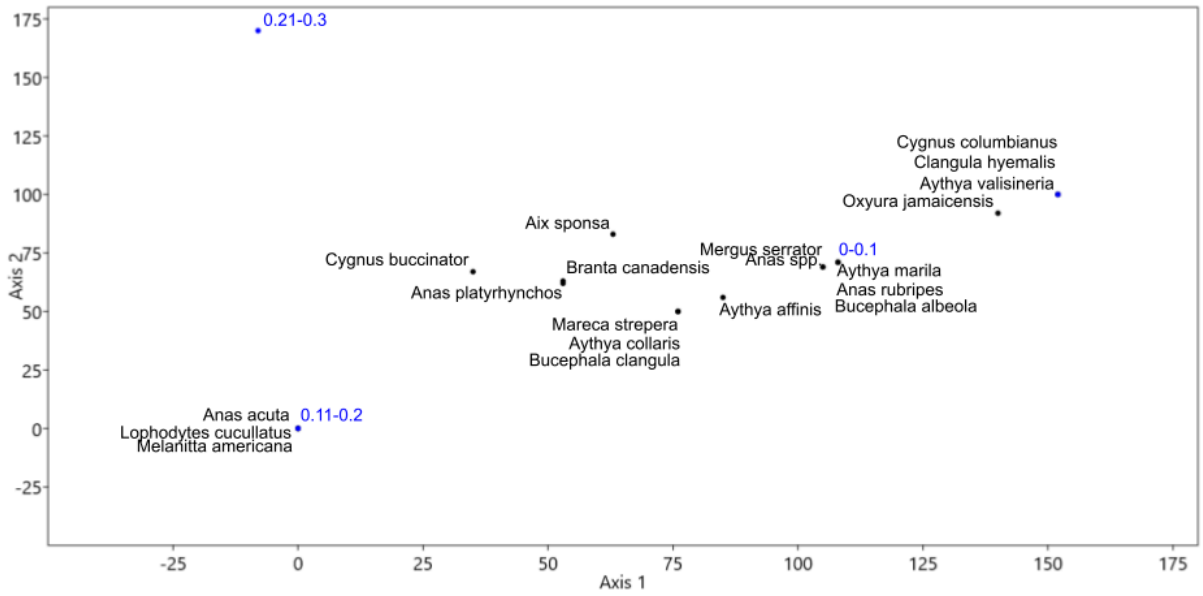

Figure 2. Detrended correspondence analysis for waterfowl intake species and monthly precipitation averages (in).

Detrended correspondence analysis found that precipitation somewhat decreased along axis 1 (Fig 2). Precipitation zone 0-0.1 inches had an axis 1 value of 152 (Fig 2). Precipitation zone 0.11-0.2 inches had an axis 1 value of 0 (Fig 2). Precipitation zone 0.21-0.3 inches had an axis 1 value of 0 (Fig 2). *Anas acuta*, *Lophodytes cucullatus*, and *Melanitta americana* were close to zone 0.11-0.2 inches (Fig 2). *Aythya marila*, *Anas rubripes*, and *Bucephala albeola* were close to zone 0-0.1 inches (Fig 2). No species were near zone 0.21-0.3 inches (Fig 2).

Axis	Eigenvalue
1	0.03241
2	0.005437
3	0.0002128
4	0.0001436

Table 5. Detrended correspondence analysis eigenvalues for waterfowl intake species and monthly precipitation averages (in).

Using detrended correspondence analysis, I found that 3.24% of the variance in abundance of waterfowl species can be explained by monthly precipitation averages (Table 5).

	Precipitation (inches)		
Intake Reason	0.00-0.10	0.11-0.20	0.21-0.30
Orphan	541	1702	211
Hit by car	94	113	31
Collision	12	5	2
Human raised	31	35	30
Cat attack	8	20	5
Dog attack	4	10	3
Bird attack	2	2	2
Trapped/litter/landlocked	46	74	25
Oil/chemical	15	4	46
Shot	3	7	0
Injury	116	106	34
Behavioral stranding	22	26	1
Failure to thrive/maladaptation	43	41	15
Other	65	42	19

Table 6. Intake reason for all waterfowl in 3 precipitation zones (in).

The most common intake reasons were orphaned, hit by car, and other (unspecified reason) injuries (Table 6). The most waterfowl taken in for these reasons occurred during months with an average precipitation of 0-0.2 inches (Table 6). The least common reason for intake was an attack by another bird (Table 6). All reasons for intake, as written by Lake Erie Nature and

Science Center, were included regardless of association with meteorology (Table 6).

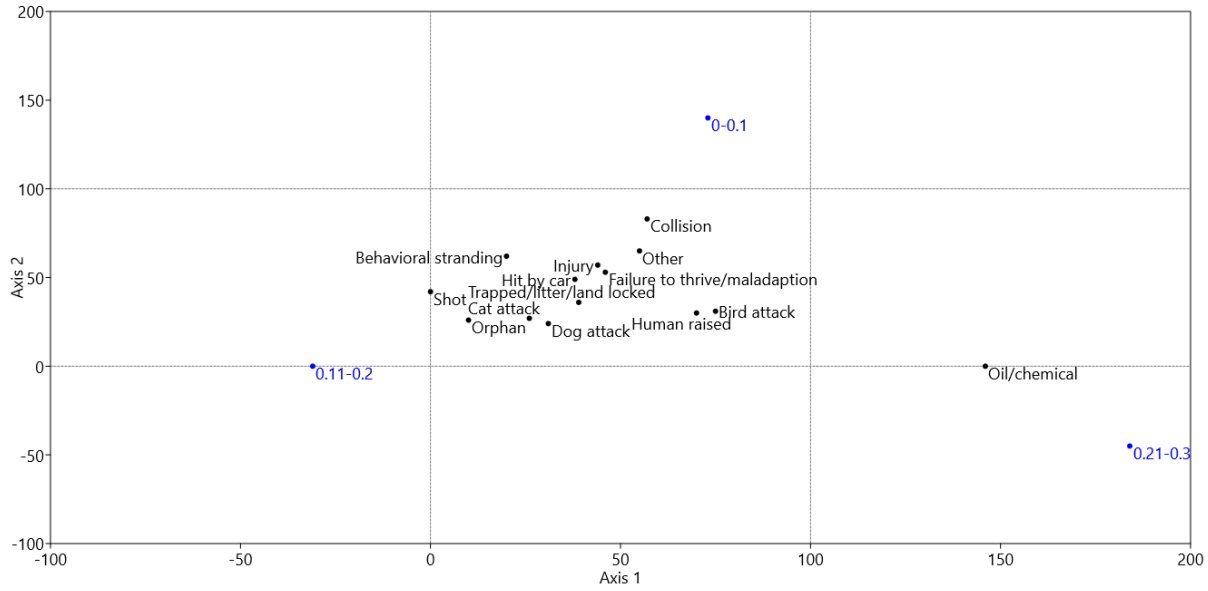

Figure 3. Detrended correspondence analysis for waterfowl intake reason and monthly precipitation averages (in).

Detrended correspondence analysis found that precipitation neither decreased nor increased across axis 1 (Fig 3). Precipitation zone 0-0.1 inches had an axis 1 value of 73 (Fig 3). Precipitation zone 0.11-0.2 inches had an axis 1 value of -31 (Fig 3). Precipitation zone 0.21-0.3 inches had an axis 1 value of 184 (Fig 3).

Axis	Eigenvalue
1	0.1015
2	0.006439
3	0.002177
4	0.001653

Table 7. Detrended correspondence analysis eigenvalues for waterfowl intake reason and monthly precipitation averages (in).

Using detrended correspondence analysis, I found that 10.15% of the variance in intake reasons for waterfowl can be explained by monthly precipitation averages (Table 7).

	Temperature (℉)			
Intake Reason	0.0-30.0	30.1-50.0	50.1-70.0	70.1+
Orphan	0	146	1044	422
Hit by car	5	69	93	71
Collision	3	11	1	4
Human raised	1	3	36	56
Cat attack	0	3	17	12
Dog attack	0	0	11	6
Bird attack	1	0	6	0
Trapped/litter/ land locked	10	17	58	60
Oil/chemical	7	3	9	46
Shot	1	6	1	2
Injury	22	60	90	84
Behavioral stranding	12	4	24	9
Failure to thrive/malada ptation	15	21	18	45
Other	16	25	38	47

Table 8. Intake reason for all waterfowl in 4 temperature zones (°F).

The most waterfowl taken in for the reasons of being orphaned, hit by a car, or injured occurred during months with an average temperature 50.1-70.1+ °F (Table 8).

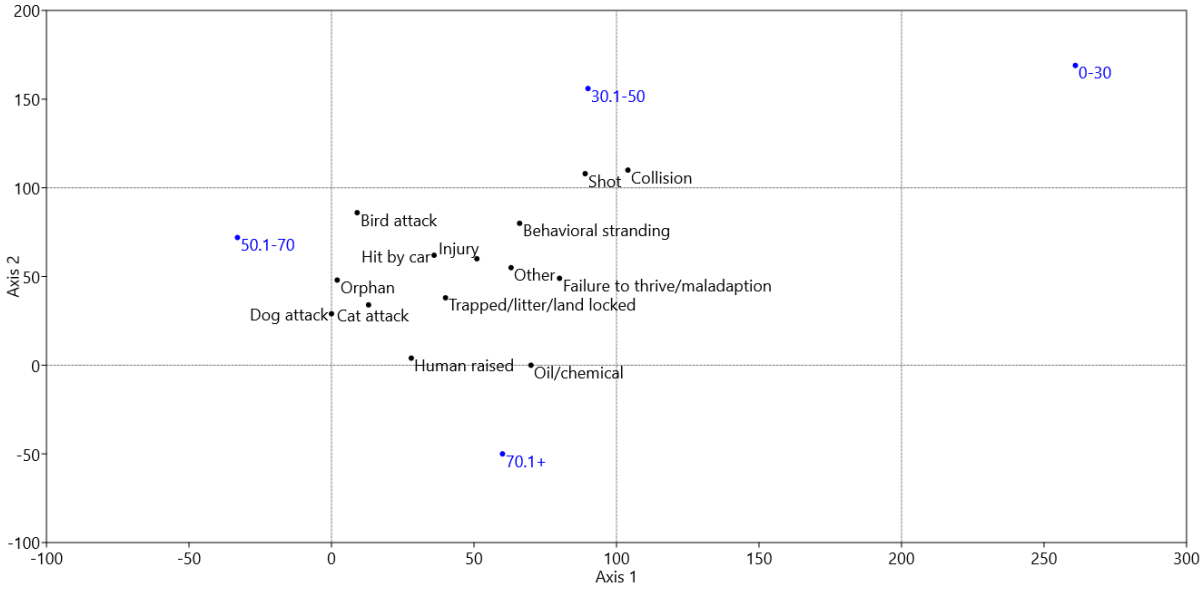

Figure 4. Detrended correspondence analysis for waterfowl intake reason and monthly temperature averages (°F).

Detrended correspondence analysis found that temperature neither decreased nor increased across axis 1 (Fig 4). Temperature zone 0-30 °F had an axis 1 value of 261 (Fig 4). Temperature zone 30.1-50 °F had an axis 1 value of 90 (Fig 4). Temperature zone 50.1-70 °F had an axis 1 value of -33 (Fig 4). Temperature zone 70.1+ °F had an axis 1 value of 60 (Fig 4). All reasons for intake were between temperature zones 30.1-70.1+ °F (Fig 4).

Axis	Eigenvalue
1	0.1533
2	0.0211
3	0.004171
4	0.001701

Table 9. Detrended correspondence analysis eigenvalues for waterfowl intake reason and monthly temperature averages.

Using detrended correspondence analysis, I found that 15.33% of the variance in intake reasons of waterfowl can be explained by monthly temperature averages (Table 9).

	Precipitation (inches)		
Age	0.00-0.10	0.11-0.20	0.21-0.30
Adult	240	231	57
Fledgling	197	186	155
Nestling	535	932	269
Egg	2	0	0

Table 10. Age of waterfowl in three precipitation zones (in).

The highest intakes for younger waterfowl were seen in hatchling and juvenile age groups during precipitation averages of 0.11-0.2 inches (Table 10). Adults were most often taken in during precipitation averages between 0.0 and 0.2 inches (Table 10). Eggs were only taken in during months with an average precipitation of 0-0.1 inches (Table 10).

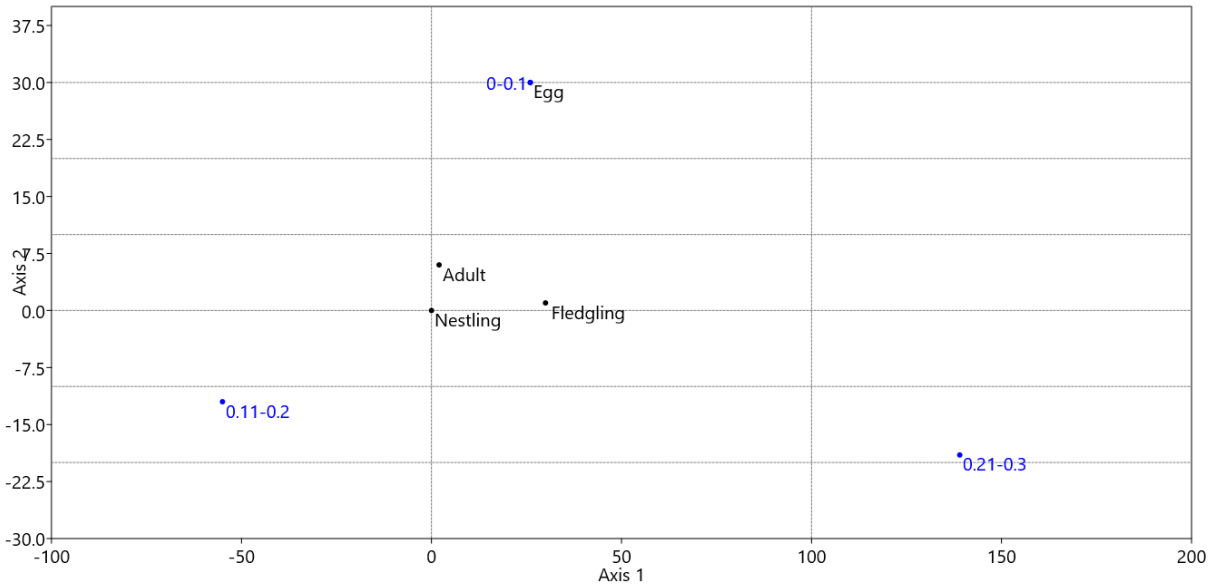

Figure 5. Detrended correspondence analysis of waterfowl age group and monthly precipitation averages (in).

Detrended correspondence analysis found that precipitation neither increased nor decreased across axis 1 (Fig 5). Precipitation zone 0-0.1 inches had an axis 1 value of 26 (Fig 5). Precipitation zone 0.11-0.2 inches had an axis 1 value of -55 (Fig 5). Precipitation zone 0.21-0.3 inches had an axis 1 value of 139 (Fig 5).

Axis	Eigenvalue
1	0.02819
2	0.004576
3	5.61E-05
4	2.49E-05

Table 11. Detrended correspondence analysis eigenvalues for waterfowl age and monthly precipitation averages (in).

Using detrended correspondence analysis, I found that 2.82% of the variance in age of waterfowl can be explained by monthly precipitation averages (Table 11).

	Temperature (℉)			
Age	0.0-30.0	30.1-50.0	50.1-70.0	70.1+
Adult	84	181	144	120
Fledgling	2	25	226	293
Nestling	0	160	1130	449
Egg	0	0	0	2

Table 12. Age of waterfowl in four temperature zones (°F).

Younger waterfowl age groups were most often taken in during temperature averages of 50.1-70.1+ °F (Table 12). Only adults and fledglings were taken in during months with a temperature average of 0-30 °F (Table 12).

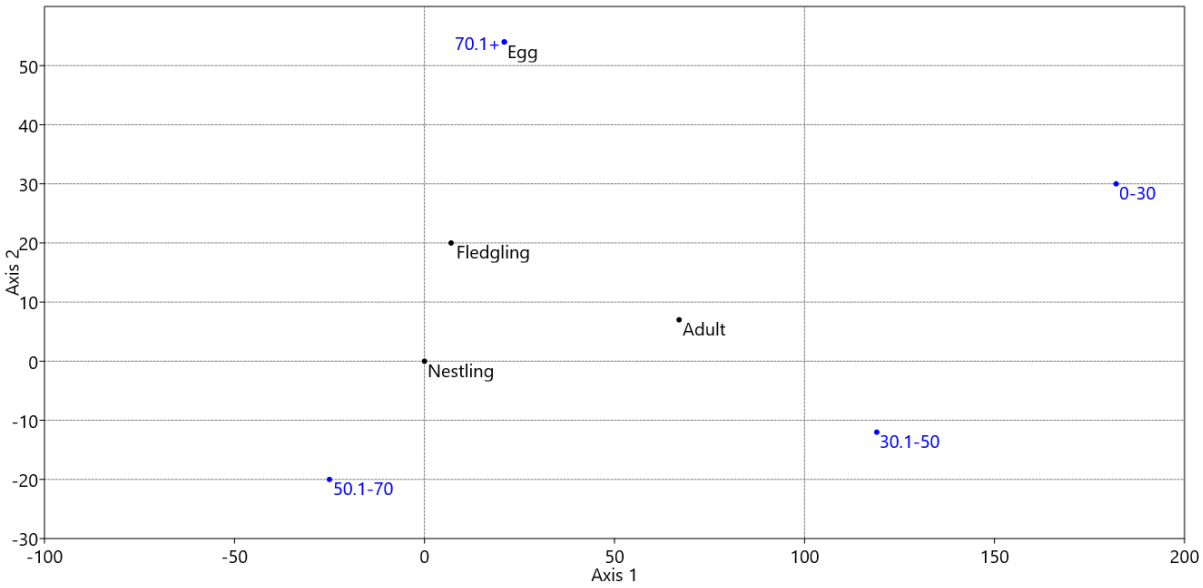

Figure 6. Detrended correspondence analysis for waterfowl intake age and monthly temperature averages (°F).

Detrended correspondence analysis found that temperature neither decreased nor increased across axis 1 (Fig 6). Temperature zone 0-30 °F had an axis 1 value of 182 (Fig 6). Temperature zone 30.1-50 °F had an axis 1 value of 119 (Fig 6). Temperature zone 50.1-70 °F had an axis 1 value of -26 (Fig 6). Temperature zone 70.1+ °F had an axis 1 value of 21 (Fig 6). The age group egg was close to the temperature range 70.1+ °F on axis 1 (Fig 6).

Axis	Eigenvalue
1	0.239
2	0.0184
3	8.77E-18
4	5.39E-33

Table 13. Detrended correspondence analysis eigenvalues for waterfowl age and monthly temperature averages.

Using detrended correspondence analysis, I found that 23.9% of the variance in age of waterfowl can be explained by monthly temperature averages (Table 13).

		Average Monthly Precipitation (in)			
		0.00-0.10	0.11-0.20	0.21-0.30	Total
Average Monthly Temperature (°F)	0.0-30.0	57	6	0	63 (1.89%)
	30.1-50.0	80	346	114	540 (16.23%)
	50.1-70.0	630	998	181	1809 (54.37%)
	70.1+	376	314	225	915 (27.50%)
	Total	1143 (34.36%)	1664 (50.02%)	520 (15.63%)	

Table 14. Number and percentage of total waterfowl taken in during zones of precipitation (in) and temperature (°F) monthly averages.

No waterfowl were taken in during the months with both an average precipitation of 0.21-0.30 inches and a temperature of 0-30 °F (Table 14). 50.02% of waterfowl was taken in during months with an average precipitation of 0.11-0.20 inches and 54.37% during months with an average temperature of 50.1-70.0 °F (Table 14).

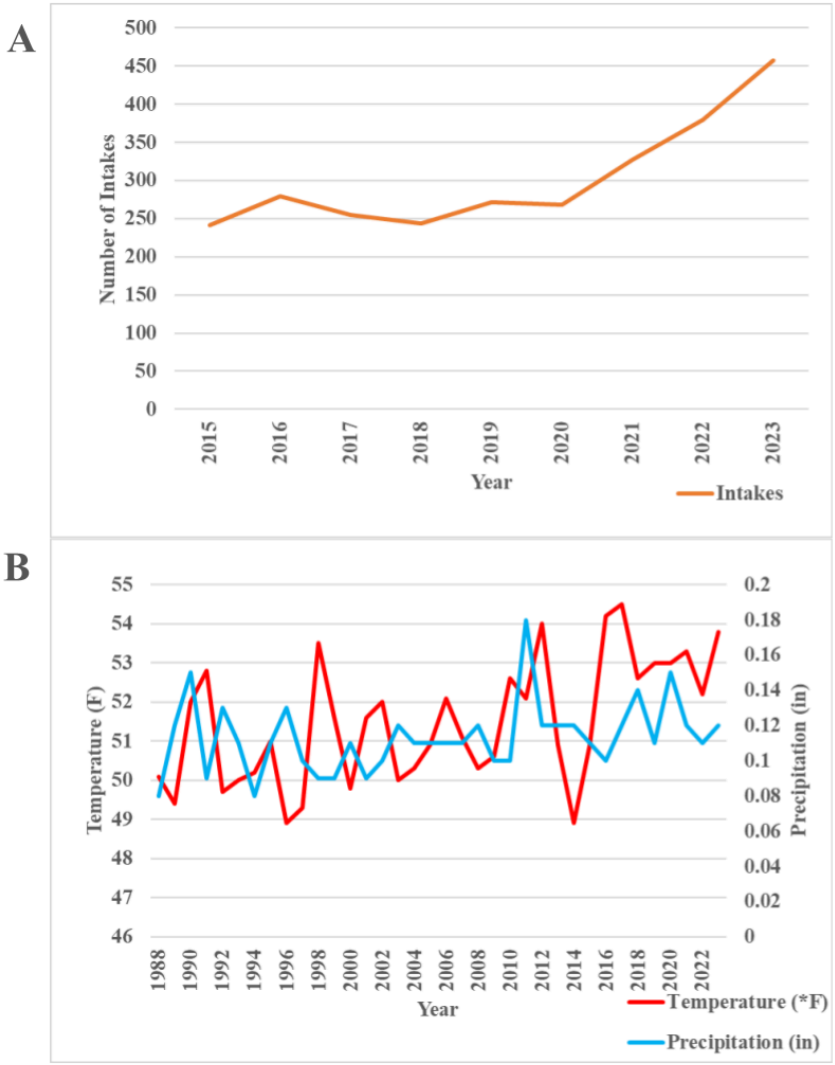

Figure 7. Number of waterfowl intakes from 2015 to 2023 (A). Average annual temperature (□F) and precipitation (in) from 1987 to 2023 (B).

Average temperatures and precipitation have been steadily increasing since at least the 1980s in the Cleveland, Ohio region (Fig 7) Number of waterfowl intakes have been increasing since 2015 (Fig 7).

5 | DISCUSSION

5.1 Limitations

The scale and detail of my results were limited by what data was available from the Lake Erie Nature and Science Center. I was particularly limited by missing data as years' worth of physical data was disposed of following protocol. All records were available from 2015 to 2023 because the record system transferred to digital. All records from before 2011 were randomly assorted or from previous data compiling. Older data records were often without much information for intake; records from before 1987 often did not list the reason for intake or species of waterfowl. Because of my limited span of years, I was unable to determine if there was a shift in the seasonal time of year for waterfowl intakes.

When looking at a species not commonly seen as “charismatic,” like waterfowl, it is possible that intake data does not accurately reflect what is going on in the wild. As the Lake Erie Nature and Science Center depends on civilians to bring in wildlife, the species brought in and the reasons for bringing them in could be biased. Wildlife species have different economic, cultural, and personal values to humans (Chardonnet et al., 2002). An animal may be more likely to be brought in depending on how willing citizens are to handle the injured animal (Long et al., 2020; Miller et al., 2023). The location of the animal also plays an important role in what is brought into rehabilitation; people are more likely to find animals in need of help in heavily trafficked areas (Long et al., 2020; Miller et al., 2023). Thus, I could expect to see more cases of animals hit by cars, versus diseased animals in the woods. With a similar rationale, the reasons for intake account for very few individuals who died before being found. Based on records, citizens very rarely bring in animals that are already deceased. Numerous records showed

ducklings being brought in after their mother was fatally hit by a car, with no record of the mother. This means that I do not know how many animals were truly affected by each reason.

5.2 Hypotheses

I hypothesized that changing climate would shift the population and health conditions we saw in waterfowl. Reason for intake, did have variance that could be explained by precipitation (Table 6) and temperature (Table 8), but not by a large amount. I could not look at shifting populations because of limited data and therefore cannot say whether my hypothesis was supported for that portion. It was thought that higher precipitation rates would result in more waterfowl intakes, but this could not be supported due to limited data. More waterfowl were taken in with warmer temperatures and more precipitation, but not at my most extreme zones (Table 13). During months with my lowest temperature zone and highest precipitation zone, waterfowl came in the least (Table 13).

My findings showed that part of the variance in waterfowl species composition, number of intakes, and intake reasons could be explained by meteorological fluctuations as expected in my hypothesis. Temperature explained close to 21% of the variance I saw in waterfowl species composition (Table 2), while precipitation explained a little over 3% of the variance (Table 4). Similarly, Cohen and Zuckerberg (2020), found that avian species distribution was more influenced by temperature than precipitation monthly. Most common species of waterfowl taken in were *Anas platyrhynchos*, *Branta canadensis*, and *Aix sponsa* (Table 1). The most waterfowl was taken in by the rehabilitation center when the average temperature was between 50.1 and 70.0 °F (Table 1) and precipitation was between 0.11 and 0.2 inches (Table 3). For the temperature and precipitation zones above those (70.1°F and above and 0.21 to 0.3 inches), only four species out of the twenty were taken in: *Aix sponsa*, *Anas platyrhynchos*, *Branta*

canadensis, and *Cygnus buccinator* (Table 1; Table 3). *Anas spp.* were taken in within the given temperature range (Table 1), but not the precipitation range (Table 3). This is not due to the listed species migrating into the area during months with those usual averages as *Aix sponsa*, *Anas platyrhynchos*, *Branta canadensis*, and *Cygnus buccinator* are in the northern Ohio region year-round (Cornell Lab of Ornithology, 2024). It is also not due to them being year-round species in the region as other species that are year-round did not come into the rehabilitation center during those average ranges (Table 1; Table 3). Individuals of these species may be expected to need wildlife rehabilitation more frequently with rising temperatures.

I found that precipitation could explain just over 10% of the variation seen in the intake reason for waterfowl (Table 6), while temperature could explain over 15% of the variation (Table 8). Despite my findings of low explanation from precipitation, there have been documented cases of temperature being linked to the death of water birds (Piatt et al., 2020). The most common reason for intake of waterfowl was that they were orphaned, hit by a car, and other injuries (Table 5; Table 7). My findings match that of Miller et al. (2023) who found that the most common reason for intake of all animals at a wildlife rehabilitation center was human disturbance (particularly vehicle collisions), orphaned, unknown, or other. Hanson et al., also found that orphan and trauma were the most common cause of waterfowl admissions (2021). Other injuries had unspecified reasons and were often listed as fractures to a particular part of the body. Being caught by a cat was not a common reason for intake (Table 5; Table 7) and did not show a seasonal difference despite previous studies finding that free-roaming cats were a main cause for avian rehabilitation and is centered around the summer months (Mcruer et al., 2016). A fair number of orphaned waterfowl had lost their parents to cars which often were not brought in and counted as they were already deceased. These most common intake reasons often occurred

within precipitation zones between 0.0 and 0.2 inches (Table 5) and temperatures between 50.1 and 70.1+ °F (Table 7). The least common reason for intake was an attack by another bird which was usually attacked by a hawk (Table 5; Table 7). Collision as a reason for intake included waterfowl that collided with stationary man-made structures like power lines and windows. The category "other" included a list of ailments such as crop stasis, dehydration, and neurological issues. The last two may be connected to disease in some cases, but this is not known. Other studies have found seasonality differences in poisoning of waterfowl and waterbirds (Grade et al., 2018; Hudson et al., 1984; Sears, 1988). Oil/chemical were far closer to the precipitation range of 0.21 to 0.3 inches than any other (Figure 4). This could be explained by increased runoff of oils and chemicals into waterways (Khan et al., 2006). It is important to note that a large number of records did not have any reason for intake listed and were therefore not included in this part of the analysis.

The waterfowl intake age was often up to interpretation by the wildlife staff doing the intake. Age categories used in the intake forms were adult, young, juvenile, nestling, chick, duckling, egg, fledgling, gosling, and hatchling. Some of these groups most likely fit into the same age range, but I could not be sure. Age groups in this study were compiled into groups egg, nestling (assumedly still residing in the nest), fledgling (assumedly venturing out of the nest), and adult. Nestling included hatchling, chick, and nestling. Fledgling included young, juvenile, duckling, gosling, and fledgling.

I found that precipitation almost 3% of the time and temperature almost 24% of the time could explain variance in age at intake. The most common age group taken in was nestlings (Table 9). Most waterfowl intakes occurred during months that had a precipitation average between 011 and 0.2 inches and/or a temperature average between 50.1 and 70 °F. Younger

waterfowl would only be taken in during times of raising young, commonly in May and June which are usually during my warmest temperature zone (Cornell Lab of Ornithology, 2024). Many other studies have looked at age as a variable for likelihood of survival (Cope et al., 2022; Costa et al., 2023; Miller et al., 2023). Age as a variable for intake is an area that needs to be studied more.

5.3 Meteorology & Location

By using the National Weather Service's temperature and precipitation data, I did find that both precipitation and temperature have been overall increasing, with great fluctuations, in the Cleveland, Ohio region over my period. The rehabilitation center has also seen a significant increase in the number of waterfowl intakes since the 1980s. This number experienced its greatest increase following the introduction of avian influenza to North America in 2021. Many rehabilitation centers stopped taking in waterfowl following the introduction of the disease, but the Lake Erie Nature and Science Center began taking in more waterfowl. Between the years 2011 and 2014, there was a large decrease in average annual temperature by over 5 ℉. This was followed by a large increase of close to 6 ℉. Only a few records were found from 2011 to 2014 so I cannot speculate on intake number fluctuations during this drop in temperature. During the temperature increase from 2014 to 2017, there was no drastic change in the number of waterfowl intakes. Overall, most waterfowl were taken in during May, June, and July for every year except 2016 which experienced a large number of intakes in April and 1989 in January.

A majority of the waterfowl taken in were found in the Cuyahoga and Lorain counties. A total of 3,465 intakes were recorded between the years of 1977 and 2023. Out of those 1,480 were from Cuyahoga County and 586 were from Lorain county. There was a total of 38 different counties from which waterfowl came from.

5.4 Broader Connections

I found that temperature does explain some of the variance I see in waterfowl intakes at one wildlife rehabilitation center. While waterfowl are commonly brought into this rehabilitation center, it is one of the many groups of animals that come into wildlife rehabilitation centers in need of attention. This rehabilitation center and many more globally work with most native species that may be impacted by rising temperatures (Fischer & Schär, 2010; Miralles et al., 2014; Pörtner et al., 2022; Vose et al., 2017; Wehrli et al., 2019). While aquatic ecosystems are important to focus on due to rising water temperatures, fluctuations in water levels, and larger ecosystem shifts, terrestrial ecosystems are facing similar challenges (Allen et al., 2005; Pörtner et al., 2022; Van Vliet et al., 2013). Meteorological shifts impact every species through health and changes to ecosystems (Doherty et al., 2016; Urban, 2015; Woinarski et al., 2015). Rehabilitation centers worldwide should expect continuing shifts in what species they are seeing and possibly the reasons and ages of those species. This speaks to the health of ecosystems as a whole. More wildlife in need of assistance means that ecosystems are failing in some or numerous ways. With global climate change, the meteorological impacts that are affecting these systems will continue to worsen (Pörtner et al., 2022; Trenberth, 2011; Van Aalst, 2006; Vose et al., 2017).

5.5 Future Research

Future research should focus on working with more rehabilitation centers in the area. Acquiring more data, especially from years with little to none, should be a main priority. Expanding the research area to encompass more than the northeastern region of Ohio would help make this research more generalizable. Furthermore, there are lots of other variables that should be considered like weight at intake and type of disposition (death or release). Previous studies

found that the distribution of birds in extreme weather events depended on each species' natural range (Cohen & Zuckerberg, 2020). Waterfowl species with larger ranges should be compared to those with smaller ranges for intake data in association with extreme weather conditions.

6 | CONCLUSION

Through this research, I illustrated that temperature and precipitation can explain some of the variation I see in waterfowl intakes at a wildlife rehabilitation center. Temperature could be an indicator of species composition, reasons, and age at intake in waterfowl. Precipitation could not act as an indicator for any of this variation, but was linked to specific species and reasons for intake. As a wildlife rehabilitation center and waterfowl specialist, the Lake Erie Nature and Science Center can utilize these findings to prepare for increasingly warming temperatures and extreme meteorological shifts with climate change. These findings could also aid in other wildlife rehabilitation centers' preparation and be generalized to other species. This information can help by providing a foundation for what to expect regarding species composition, intake reason, and age. As a building block, this can aid in figuring out what the Lake Erie Nature and Science Center can focus future research on. Expecting more waterfowl with increasing temperatures is a reason to allocate more funds to the resources necessary for waterfowl rehabilitation. Specific species may be expected and prepared ahead of time. Findings on the reason for intakes can be used to improve public education and possibly reduce anthropogenic impacts. Lots of future research is necessary to better understand how species composition and intakes will shift at the Lake Erie Nature and Science Center with climate change, but these results are a first step.

7 | REFERENCES

Allan, J. D., Palmer, M., & Poff, N. L. (2005). Climate change and freshwater ecosystems. *Climate Change and Biodiversity*, 274-290.

Arnell, N. W., & Gosling, S. N. (2013). The impacts of climate change on river flow regimes at the global scale. *Journal of Hydrology*, 486, 351-364.

Ashmore, P., & Church, M. (2000). The impact of climate change on rivers and river processes in Canada.

Bailey, P. C. E., Boon, P. I., Blinn, D. W., & Williams, W. D. (2006). Salinization as an ecological perturbation to rivers, streams and wetlands of arid and semi-arid zones. *Changeable, Changes, Changing: the Ecology of Rivers from the World's Dry Regions*, 280-314.

Blakely, N. (2019). Great Black Swamp: Drained centuries ago, DNR and Ohio organizations look to bring some of it back. *Great Lakes Now*.

Bongers, J. H., & Tetenburg, G. J. (1996). Botulism in waterfowl. *Veterinary Quarterly*, 18, 156-157.

Cañedo-Argüelles, M., B. J. Kefford, C. Piscart, N. Prat, R. B. Schafer,and C. J. Schulz. 2013. Salinisation of rivers: an urgent ecological issue. Environmental Pollution 173: 157–167.

Carpenter, S. R., Fisher, S. G., Grimm, N. B., & Kitchell, J. F. (1992). Global change and freshwater ecosystems. *Annual Review of Ecology and Systematics*, 119-139.

Chardonnet, P., Clers, B. D., Fischer, J., Gerhold, R., Jori, F., & Lamarque, F. (2002). The value of wildlife. *Revue scientifique et technique-Office international des épizooties*, 21(1), 15-52.

Cohen, J. M., Fink, D., & Zuckerberg, B. (2020). Avian responses to extreme weather across functional traits and temporal scales. *Global Change Biology*, 26(8), 4240-4250.

Cope, H. R., McArthur, C., Dickman, C. R., Newsome, T. M., Gray, R., & Herbert, C. A. (2022). A systematic review of factors affecting wildlife survival during rehabilitation and release. *PLoS One*, 17(3).

Cornell Lab of Ornithology. (2024). All about birds. *Cornell Lab of Ornithology, Ithaca, New York*. https://www.allaboutbirds.org

Costa, M. M., Pinto da Cunha, N., Hagnauer, I., & Venegas, M. (2023). A retrospective analysis of admission trends and outcomes in a wildlife rescue and rehabilitation center in Costa Rica. *Animals*, 14(1), 51.

Dahl, T.E. (1990) Wetlands losses in the United States, 1780s to 1980s. *U.S. Department of Interior, Fish and Wildlife Service, Washington, DC.*

Dahl, T.E. (2006) Status and trends of wetlands in the conterminous United States 1998 to 2004. *U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC.*

Dahl, T.E. & Johnson, C.E. (1991) Wetlands status and trends in the conterminous United States mid-1970s to mid-1980s. *U.S. Department of Interior, Fish and Wildlife Service, Washington, DC.*

Doherty, T. S., Glen, A. S., Nimmo, D. G., Ritchie, E. G., & Dickman, C. R. (2016). Invasive predators and global biodiversity loss. *Proceedings of the National Academy of Sciences*, 113(40), 11261-11265.

Donat, M. G., Lowry, A. L., Alexander, L. V., O'Gorman, P. A., & Maher, N. (2016). More extreme precipitation in the world's dry and wet regions. *Nature Climate Change*, 6(5), 508-513.

Dorak, B. E., Ward, M. P., Eichholz, M. W., Washburn, B. E., Lyons, T. P., & Hagy, H. M. (2017). Survival and habitat selection of Canada Geese during autumn and winter in metropolitan Chicago, USA. *The Condor: Ornithological Applications*, 119(4), 787-799.

Earnst, S. L., & Rothe, T. C. (2004). Habitat selection by Tundra Swans on northern Alaska breeding grounds. *Waterbirds*, 27(2), 224-233.

Elser, J. J., Bracken, M. E. S., Cleland, E. E. ,Gruner, D. S. , Harpole, W. S., Hillebrand, H., Ngai, J. T., Seabloom, E. W., Shurin, J. B., & Smith, J. E. (2007). Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems. *Ecology Letters*, 10, 1135–1142.

Fischer, E. M., & Schär, C. (2010). Consistent geographical patterns of changes in high-impact European heatwaves. *Nature Geoscience*, 3(6), 398-403.

Fisher, S. G., Gray, L. J., Grimm, N. B., & Busch, D. E. (1982). Temporal succession in a desert stream ecosystem following flash flooding. *Ecological Monographs*, 52(1), 93-110.

Goel, P. K. (2006). Water pollution: causes, effects and control. *New Age International*.

Grade, T. J., Pokras, M. A., Laflamme, E. M., & Vogel, H. S. (2018). Population‐level effects of lead fishing tackle on common loons. *The Journal of Wildlife Management*, 82(1), 155-164.

Gregory, R. D., & van Strien, A. (2010). Wild bird indicators: using composite population trends of birds as measures of environmental health. *Ornithological Science*, 9(1), 3-22.

Han, G., Sun, B., Chu, X., Xing, Q., Song, W., & Xia, J. (2018). Precipitation events reduce soil respiration in a coastal wetland based on four-year continuous field measurements. *Agricultural and Forest Meteorology*, 256, 292-303.

Hanson, M., Hollingshead, N., Schuler, K., Siemer, W. F., Martin, P., & Bunting, E. M. (2021). Species, causes, and outcomes of wildlife rehabilitation in New York State. *PLoS One*, 16(9).

Hansson, L. A., Bronmark, C., Nilsson, P. A., & Abjornsson, K. (2005). Conflicting demands on wetland ecosystem services: nutrient retention, biodiversity or both? *Freshwater Biology* 50: 705–714.

Heitmeyer, M. E., & Vohs Jr, P. A. (1984). Distribution and habitat use of waterfowl wintering in Oklahoma. *The Journal of Wildlife Management*, 51-62.

Hénaux, V., & Samuel, M. D. (2011). Avian influenza shedding patterns in waterfowl: implications for surveillance, environmental transmission, and disease spread. *Journal of Wildlife Diseases*, 47(3), 566-578.

Henry, D. A., Ament, J. M., & Cumming, G. S. (2016). Exploring the environmental drivers of waterfowl movement in arid landscapes using first-passage time analysis. *Movement Ecology*, 4, 1-18.

Herbert, E., Boon, P., Burgin, A. J., Neubauer, S. C., Franklin, R. B., Ardon, M., Hopfensberger, K. N., Lamers, L. P. M., & Gell, P. (2015). A global perspective on wetland salinization: Ecological consequences of a growing threat to freshwater wetlands. *Ecosphere*, 6.

Herdendorf, C. E. (1992). Lake Erie coastal wetlands: an overview. *Journal of Great Lakes Research*, 18(4), 533-551.

Hess, J. C., & Paré, J. A. (2004). Viruses of waterfowl. *Avian and Exotic Pet Medicine*, 13 (4), 176-183.

Higgins, S. N., Malkin, S. Y., Todd Howell, E., Guildford, S. J., Campbell, L., Hiriart‐Baer, V., & Hecky, R. E. (2008). An ecological review of *Cladophora glomerata* (Chlorophyta) in the Laurentian Great Lakes 1. *Journal of Phycology*, 44(4), 839-854.

Hollmen, T. E., Flint, P. L., Ulman, S. E., Wilson, H. M., Amundson, C. L., & Osnas, E. E. (2023). Climate change and coastal wetland salinization: Physiological and ecological consequences for Arctic waterfowl. *Functional Ecology*.

Hudson, R. H., Haegele, M. A., & Tucker, R. K. (1984). Handbook of toxicity of pesticides to wildlife. *US Department of the Interior, Fish and Wildlife Service*, 153.

Hüppop, O. & Hüppop, K. (2003). North Atlantic oscillation and timing of spring migration in birds. *Proceedings of the Royal Society B*, 270:233–240.

Jonzén, N., Lindén, A., Ergon, T., Knudsen, E., Vik, J. O., Rubolini, D., Piacentini, D., Brinch, C., Spina, F., Karlsson, L., Stervander, M., Andersson, A., Waldenström, J., Lehikoinen, A., Edvardsen, E., Solvang, R., Stenseth, N. C. (2006) Rapid advance of spring arrival dates in long-distance migratory birds. *Science* 312:1959–1961.

Kaatz, M. R. (1955). The Black Swamp: a study in historical geography. *Annals of the Association of American Geographers*, 45(1), 1-35.

Keeling, C. D., & Whorf, T. P. (1994). Atmospheric CO2 records from sites in the SIO air sampling network. *Trends*, 93, 16-26.

Khan, S., Lau, S. L., Kayhanian, M., & Stenstrom, M. K. (2006). Oil and grease measurement in highway runoff—sampling time and event mean concentrations. *Journal of Environmental Engineering*, 132(3), 415-422.

Lehikoinen, A., & Jaatinen, K. (2012). Delayed autumn migration in northern European waterfowl. *Journal of Ornithology*, 153, 563-570

Lehmann, J., Coumou, D., & Frieler, K. (2015). Increased record-breaking precipitation events under global warming. *Climatic Change*, 132(4), 501-515.

Long, R.B., Krumlauf, K., & Young, A.M. (2020). Characterizing trends in human-wildlife conflicts in the American Midwest using wildlife rehabilitation records. *PLoS ONE*, 15(9). https://doi.org/10.1371/journal.pone.0238805

Loyn, R. H., Rogers, D. I., Swindley, R. J., Menkhorst, P. W., Stamation, K., Haynes, S., Graham, H., & Steele, W. K. (2023). Waterfowl populations decline with nutrient reduction and increase with nutrient restoration: 20 years of adaptive management at a Ramsar-listed wastewater treatment plant. *Hydrobiologia*, 1-21.

Lutz, M. J., Caldeira, K., Dunbar, R. B., Behrenfeld, M. J. (2007). Seasonal rhythms of net primary production and particulate organic carbon flux to depth describe the efficiency of biological pump in the global ocean. *Journal of Geophysical Research*, 112.

Masto, N. M., Robinson, O. J., Brasher, M. G., Keever, A. C., Blake‐Bradshaw, A. G., Highway, C. J., Fedderson, J. C., Hagy, H. M., Osborne, D. C., Combs, D. L., & Cohen, B. S. (2022). Citizen science reveals waterfowl responses to extreme winter weather. *Global Change Biology*, 28(18), 5469-5479.

McCartney, M. (2009). Living with dams: managing the environmental impacts. *Water Policy*, 11(S1), 121-139.

Mcruer, D. L., Gray, L. C., Horne, L. A., & Clark Jr, E. E. (2017). Free‐roaming cat interactions with wildlife admitted to a wildlife hospital. *The Journal of Wildlife Management*, 81(1), 163-173.

Michalak, A. M., Anderson, E. J., Beletsky, D., Boland, S., Bosch, N. S., Bridgeman, T. B., Chaffin, J. D., Cho, K., Confesor, R., Daloğlu, I., DePinto, J. V., Evans, M. A.,

Fahnestiel, G. L., He, L., Ho, J. C., Jenkins, L., Johengen, T. H., Kuo, K. C., LaPorte, E., Liu, X., McWilliams, M. R., Moore, M. R., Posselt, D. J., Richards, R. P., Scavia, D., Steiner, A. L., Verhamme, E., Wright, D. M., & Zagorski, M. A. (2013). Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions. *Proceedings of the National Academy of Sciences*, 110(16), 6448-6452.

Miller, T. K., Pierce, K., Clark Jr, E. E., & Primack, R. B. (2023). Wildlife rehabilitation records reveal impacts of anthropogenic activities on wildlife health. *Biological Conservation*, 286, 110295.

Miralles, D. G., Teuling, A. J., Van Heerwaarden, C. C., & Vilà-Guerau de Arellano, J. (2014). Mega-heatwave temperatures due to combined soil desiccation and atmospheric heat accumulation. *Nature Geoscience*, 7(5), 345-349.

Mitcham, S. A., & Wobeser, G. (1988). Toxic effects of natural saline waters on mallard ducklings. *Journal of Wildlife Diseases*, 24, 45–50.

Mitsch, W. J., & Hernandez, M. E. (2013). Landscape and climate change threats to wetlands of North and Central America. *Aquatic Sciences*, 75, 133-149.

Monnin, E., Indermühle, A., Dällenbach, A., Flückiger, J., Stauffer, B., Stocker, T. F., Raynaud, D., & Barnola, J. M. (2001). Atmospheric CO2 concentrations over the last glacial termination. *Science*, 291, 112-114.

Moore, T. T. (2011). Climate change and animal migration. *Environmental Law*, 41, 393.

Moorman, A. M., Moorman, T. E., Baldassarre, G. A., & Richard, D. M. (1991). Effects of saline water on growth and survival of mottled duck ducklings in Louisiana. Journal of Wildlife Management, 55, 471–476.

National Center for Immunization and Respiratory Diseases (NCIRD). (2022). Avian influenza in birds. *Centers for Disease Control and Prevention*.

Neftel, A., Moor, E., Oeschger, H., & Stauffer, B. (1985). Evidence from polar ice cores for the increase in atmospheric CO2 in the past two centuries. *Nature*, 315, 45-47.

Overton, C. T., & Casazza, M. L. (2023). Movement behavior, habitat selection, and functional responses to habitat availability among four species of wintering waterfowl in California. *Frontiers in Ecology and Evolution*, 11, 1232704.

Owen, M., & Black, J. M. (1990). Waterfowl ecology. *Blackie and Son Limited*.

Palmer, M. A., Lettenmaier, D. P., Poff, N. L., Postel, S. L., Richter, B., & Warner, R. (2009). Climate change and river ecosystems: protection and adaptation options. *Environmental Management*, 44(6), 1053-1068.

Pearson, G. & Jensen, W. (1994). Waterfowl botulism--a brief summary. *Northern Prairie Wildlife Research Center*.

Piatt, J. F., Parrish, J. K., Renner, H. M., Schoen, S. K., Jones, T. T., Arimitsu, M. L., Kuletz, K.J., Bodenstein, B., García-Reyes, M., Duerr, R.S., Corcoran, R.M., Kaler, R.S.A., McChesney, G.J., Golightly, R.T., Coletti, H.A., Suryan, R.M., Burgess, H.K., Lindsey, J., Lindquist, K., Warzybok, P.M., Jahncke, J., Roletto, J., & Sydeman, W. J. (2020). Extreme mortality and reproductive failure of common murres resulting from the northeast Pacific marine heatwave of 2014-2016. *PloS one*, 15(1), e0226087.

Poff, N. L., & Ward, J. V. (1989). Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. *Canadian Journal of Fisheries and Aquatic Sciences*, 46(10), 1805-1818.

Pörtner, H. O., Roberts, D. C., Adams, H., Adler, C., Aldunce, P., Ali, E., Begum, R.A., Betts, R., Kerr, R. B., Biesbroek, R., Birkmann, J., & Fischlin, A. (2022). Climate change 2022: Impacts, adaptation and vulnerability. *IPCC Sixth Assessment Report*.

Racine, C. H., Walsh, M. E., Roebuck, B. D., Collins, C. M., Calkins, D., Reitsma, L., Buchli, P., & Goldfarb, G. (1992). White phosphorus poisoning of waterfowl in an Alaskan salt marsh. *Journal of Wildlife Diseases*, 28(4), 669-673.

Rainio, R., Laaksonen, T., Ahola, M., Vähätalo, A. V., & Lehikoinen, E, (2006). Climatic responses in spring migration of boreal and arctic birds in relation to wintering area and taxonomy. *Journal of Avian Biology*, 37:507–515.

Randall, N. J., Blitvich, B. J., & Blanchong, J. A. (2012). Efficacy of wildlife rehabilitation centers in surveillance and monitoring of pathogen activity: a case study with West Nile virus. *Journal of Wildlife Diseases*, 48(3), 646-653.

Reed, K. D., Meece, J. K., Henkel, J. S., & Shukla, S. K. (2003). Birds, migration and emerging zoonoses: West Nile virus, Lyme disease, influenza A and enteropathogens. *Clinical Medicine & Research*, 1(1), 5-12.

Schmidt-Nielsen, K., & Kim, Y. T. (1964). The effect of salt intake on the size and function of the salt gland of ducks. *Auk*, 81, 160–172.

Sears, J. (1988). Regional and seasonal variations in lead poisoning in the mute swan *Cygnus olor* in relation to the distribution of lead and lead weights, in the Thames area, England. *Biological Conservation*, 46: 115–134.

Shaw, S. P., & Fredine, C. G. (1956). Wetlands of the United States: their extent and their value to waterfowl and other wildlife. *US Department of the Interior, Fish and Wildlife Service*, 39.

Sparling, D. W., Gustafson, M., Klein, P., & Karouna-Renier, N. (1997). Toxicity of white phosphorus to waterfowl: Acute exposure in mallards. *Journal of Wildlife Diseases*, 33(2), 187-197.

Squires, J. R., Anderson, S. H., & Lockman, D. C. (1992). Habitat selection of nesting and wintering trumpeter swans. *Wildlife 2001: Populations*, 665-675.

Stolley, D. S., Bissonette, J. A., & Kadlec, J. A. (1998). Effects of saline environments on the survival of wild gosling (*Branta canadensis*). *American Midland Naturalist*, 142, 181–190.

Teitelbaum, C. S., Casazza, M. L., McDuie, F., De La Cruz, S. E., Overton, C. T., Hall, L. A., Matchett, E. L., Ackerman, J. T., Sullivan, J. D., & Prosser, D. J. (2023). Waterfowl recently infected with low pathogenic avian influenza exhibit reduced local movement and delayed migration. *Ecosphere*, 14(2).

Traill, L. W., Bradshaw, C. J., Field, H. E., & Brook, B. W. (2009). Climate change enhances the potential impact of infectious disease and harvest on tropical waterfowl. *Biotropica*, 41(4), 414-423.

Trenberth, K. E. (2011). Changes in precipitation with climate change. *Climate Research*, 47(1-2), 123-138.

United States. (1999) National Weather Service. *United States*. [Web Archive] Retrieved from the Library of Congress, https://www.loc.gov/item/lcwaN0015050/.

Urban MC. 2015. Accelerating extinction risk from climate change. *Science*, 348: 571– 573.

U.S. Fish and Wildlife Service. (2022). Waterfowl population status, 2022. *U.S. Department of the Interior*.

Van Aalst, M. K. (2006). The impacts of climate change on the risk of natural disasters. *Disasters*, 30(1), 5-18.

van Vliet, M. T., Franssen, W. H., Yearsley, J. R., Ludwig, F., Haddeland, I., Lettenmaier, D. P., & Kabat, P. (2013). Global river discharge and water temperature under climate change. *Global Environmental Change*, 23(2), 450-464.

Vose, R. S., Easterling, D. R., Kunkel, K. E., LeGrande, A. N., & Wehner, M. F. (2017). Temperature changes in the United States. *Climate Science Special Report: Fourth National Climate Assessment*.

Watson, S. B., Miller, C., Arhonditsis, G., Boyer, G. L., Carmichael, W., Charlton, M. N., Confesor, R., Depew, D. C., Höök, T. O., Ludsin, S. A., Matisoff, G., McElmurray, S. P., Murray, M.W., Richards, P. R., Rao, Y. R. Steffen, M. M., & Wilhelm, S. W. (2016). The re-eutrophication of Lake Erie: Harmful algal blooms and hypoxia. *Harmful algae*, 56, 44-66.

Wehrli, K., Guillod, B. P., Hauser, M., Leclair, M., & Seneviratne, S. I. (2019). Identifying key driving processes of major recent heat waves. *Journal of Geophysical Research: Atmospheres*, 124(22), 11746-11765.

White, D. H., & James, D. (1978). Differential use of fresh water environments by wintering waterfowl of coastal Texas. *The Wilson Bulletin*, 99-111.

Williams, W. D. (1999). Salinisation: a major threat to water resources in the arid and semi-arid regions of the world. *Lakes and Reservoirs: Research and Management,* 4, 85–91.

Woinarski, J. C., Burbidge, A. A., & Harrison, P. L. (2015). Ongoing unraveling of a continental fauna: decline and extinction of Australian mammals since European settlement. *Proceedings of the National Academy of Sciences*, 112(15), 4531-4540.

Woodward, G., Perkins, D. M., & Brown, L. E. (2010). Philosophical transactions of the Royal Society B: *Biological Sciences*, 365(1549), 2093-2106.

Yabsley, M. J. (2019). The role of wildlife rehabilitation in wildlife disease research and surveillance. *Medical Management of Wildlife Species: A Guide for Practitioners*, 159-165.

Zhang, X., Wan, H., Zwiers, F. W., Hegerl, G. C., & Min, S. K. (2013). Attributing intensification of precipitation extremes to human influence. *Geophysical Research Letters*, 40(19), 5252-5257.

8 | APPENDIX

Appendix 1. Example of intake records in excel format as received.

Patient	Common Species	Gender	Life	Date	Date	Details of	Circumstances of	Resc	Rescue	Rescue Address	Anatomical	Injury Comments	Weigh	Weigh	Weigh	Units
18-1679	Trumpeter Swan	Undetermin	Adult		10/22/2018		Undetermined	OH	Geauga County		Forelimb/w	Old healed frxt	43395.00		20	poun
21-01124	Trumpeter Swan	Undetermin ed	Juvenile		8/26/2021	found at park	Undetermined	OH	Lorain County	Sandy Ridge Reservation,	Musculoske letal					
23-01888	Trumpeter Swan	Female	Adult		10/17/2023		Failure to	OH	Cuyahoga		Forelimb/w	old wing injury				
23-01916	Trumpeter Swan	Undetermin ed	Juvenile		11/29/2023		Undetermined	OH	Ottawa County		Femur	Right femur fracture, took to cle zoo for	45255.00		16.1	poun ds
23-01916	Trumpeter Swan	Undetermin ed	Juvenile		11/29/2023		Undetermined	OH	Ottawa County		Femur	Right femur fracture, took to cle zoo for	45255.00		16.1	poun ds
23-01916	Trumpeter Swan	Undetermin ed	Juvenile		11/29/2023		Undetermined	OH	Ottawa County		Femur	Right femur fracture, took to cle zoo for	45255.00		16.1	poun ds
23-01916	Trumpeter Swan	Undetermin ed	Juvenile		11/29/2023		Undetermined	OH	Ottawa County		Femur	Right femur fracture, took to cle zoo for	45255.00		16.1	poun ds
23-01916	Trumpeter Swan	Undetermin ed	Juvenile		11/29/2023		Undetermined	OH	Ottawa County		Femur	Right femur fracture, took to cle zoo for	45255.00		16.1	poun ds
23-01916	Trumpeter Swan	Undetermin ed	Juvenile		11/29/2023		Undetermined	OH	Ottawa County		Femur	Right femur fracture, took to cle zoo for	45255.00		16.1	poun ds

Body	Weight	Weight Record -	Weight Record -	Weight Record -	Weight Record -	Weight Record -	Weight Record -	Disposition	Transfer	Time	Time	Date	Disposition	Disposition To
		10/22/2018		20	kilograms			Transferred	Education			11/13/2018		Hiram College
								Transferred	Education Permit			9/22/2021		Mary Nelson
								Transferred	Education			10/24/2023		Akron Zoo
		11/14/2023		16.4	kilograms			Active						
		11/18/2023		16.7	kilograms			Active						
		11/19/2023		16.7	kilograms			Active						
		11/20/2023		17	kilograms			Active						
		11/22/2023		17	kilograms			Active						
		11/25/2023		16.1	kilograms			Active						